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Dose Response of $H_p(0.07)$ on TLD-700 and TLD-900 Based Ring Dosimeters to the Sr-90 Exposure

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ABSTRACT

The preparation of radiopharmaceuticals may necessitate close contact with the radioactive source. In this case, high-energy beta-emitting nuclides can cause a high exposure. There are two methods of measuring the dose in the extremities, including using a bracelet and a ring dosimeter. In this study, the response of the Hp(0.07) dose in TLD-700 and TLD-900-based ring dosimeters to Sr-90 beta radiation was compared based on the parameters of distance, time, and angle of irradiation. The dosimeters were irradiated using Sr-90 at a distance of 5, 7, and 10 cm from the source surface and all of them were subsequently read with TLD Reader. The same type of dosimeter was exposed to Sr-90 for 1 day, 2 days, and 3 days at a distance of 7 cm, and then read. At a distance of 7 cm, the other dosimeters were irradiated at angles of 30°, 60°, -30°, and -60°, and then read. The study shows that the relationship between the distance of irradiation to $H_p(0.07)$ dose is polynomial with a correlation factor of 1, both for TLD-700 and TLD-900-based ring dosimeters. The dose response at the variation of irradiation time showed linear behavior with correlation coefficients of 0.9942 and 0.9999 for TLD-700 and TLD-900, respectively. The decrease in $H_p(0.07)$ response in TLD-700 reached 14-31 % for the irradiation angle of ±30° and 23-27 % in TLD-900 for the same angle. Meanwhile, the decrease in $H_p(0.07)$ response at the angle of irradiation ±60° reached 48 % for TLD-700 and 66-67 % for TLD-900.

INTRODUCTION

Currently, the use of radiation and radioactive substances in the medical field has grown rapidly, for example in medical imaging and nuclear medicine. However, using ionizing radiation, such as gamma or X-rays, is inevitably associated with radiogenic risk [1], for example, cataract and skin cancer. Simon et al. [2] stated that the data presented suggest that low-dose radiation exposure causes an excess risk of cancer and very likely also an excess risk of various non-cancer endpoints. Fontanillas et al. [3] validated risk prediction models for basal cell carcinoma, squamous cell carcinoma, and melanoma. They also found that high scores were not only associated with earlier diagnosis of the disease, but also with more severe and recurrent forms of skin cancer.

The preparation of radiopharmaceuticals may necessitate close contact to the radioactive source. In this case, high-energy beta-emitting nuclides can especially give high exposure [4]. Strontium-90 (Sr-90) is a fission product that decays by beta emission to Y-90, which is also a beta emitter, with the half-lives of 29 years and 64 hours, respectively [5]. When doctors and radiation workers use radiation or radioactive material, they have the potential to be exposed to high level of beta-gamma radiation and X-rays in their extremities.

In the Regulation of the Head of the Nuclear Energy Regulatory Agency No. 15 of 2014, it is stated that the dose limit value for hands or feet or skin is 150 mSv/year [6]. There are two methods of measuring the dose in the extremities, including using a bracelet and a ring dosimeter. The location of the maximum distribution of the extremity radiation dose lies in the hand, more specifically at the fingertips [7,8]. Several types of TLD-based ring

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dosimeters are used for extremity dose monitoring, e.g. Bicron (TLD-100), Mirion (TLD-100H), and Radpro (TLD-700H).

Maula et al. [8] tested the $H_p(0.07)$ response on a TLD-900 ($CaSO_4$:Dy) based ring dosimeter to Sr-90, Cs-137, and X-ray. They found that the maximum change to the normal angle is 9 % and the extremity dosimeter response is good as evidenced by the readings. Meanwhile, Luo et al. [9] tested the response of $H_p(0.07)$ on a TLD-700H (^{7}LiF:Mg,Cu,P) based ring dosimeter against beta, gamma, and X-ray. Kong et al. [10] stated that $H_p(0.07)$ is the personal dose equivalent at a depth of 0.07 mm in the tissue, which is the measurement point for skin exposure. Anggarani et al. [11] tested the response of the $H_p(3)$ TLD-900 based eye dosimeter to beta and photon radiation. TLD-100 (LiF:Mg,Ti) based ring dosimeter such as the TLD-900 is also used for eye dose measurement. Hiswara et al. [12] measured eye lens doses received by radiation workers in interventional radiology and cardiology using TLD-100.

To ensure dose evaluation competency and traceability to the international standard, intercomparison of dose response to individual monitoring service laboratories is done [13]. In this study, the response of the Hp(0.07) dose in TLD-700 and TLD-900-based ring dosimeters to Sr-90 beta radiation was compared based on the parameters of distance, time, and angle of irradiation. TLD-700 based ring dosimeter is evaluated in Laboratory for Technology of Radiation Safety and Metrology, National Research and Innovation Agency (LTRSM-NRIA), Pasar Jumat, Jakarta, Indonesia. Meanwhile, TLD-900 based ring dosimeter is evaluated in the Dosimetry Laboratory of NuklindoLab, Jakarta, Indonesia.

METHODOLOGY

Materials and instruments

A ring dosimeter is an extremity dosimeter worn on the fingertips of the hand. The detector on the ring dosimeter can be based on thermoluminescence dosimeter (TLD). In this study, Harshaw's TLD-700 and Nucleonix's TLD-900 were used as detectors. TLD-700 is made from LiF:Mg,Ti with ^{7}Li enrichment up to 99.99 % [14], while TLD-900 is made of CaSO4:Dy [8]. The TLD-700 is attached to a sandwich-shaped ring dosimeter measuring 3.2 × 3.2 × 0.89 mm, while the TLD-900 is 6 mm in diameter and 0.9 mm thick. The phantom used is a rod phantom with a diameter of 19 mm and a length of 190 mm. Ring dosimeter based on TLD-700 is manufactured by Thermo Fisher Scientific, meanwhile TLD-900 based ring dosimeter is manufactured by NuklindoLab. Figure 1 shows the ring dosimeter based on TLD-700 and TLD-900.

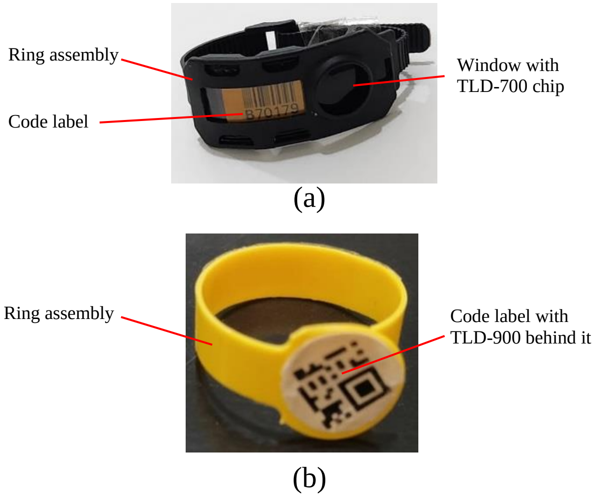


Fig. 1. Ring dosimeter based on TLD-700 (a) and based on TLD-900 (b) [8,9].

The $H_p(0.07)$ on the TLD-700 and TLD-900 based ring dosimeters were read using the Harshaw TLD Reader 6600 Plus and TLD Reader Nucleonix TL1009I with their respective applications of the TL reader software.

The Reader for the TLD-700 is capable of reading Hp(0.07) doses with an accuracy of ± 30 % at 1 mSv and ± 10 % at doses above 10 mSv. The accuracy of these dose readings does not differ in the reader for the TLD-900 [15,16]. Annealing on the TLD-900 is carried out at a temperature of 230 °C, while on the TLD-700 the annealing is carried out at a temperature of 300 °C. Meanwhile, the glow curve of dose readings on the TLD-700 and TLD-900 can be seen in Fig. 2.

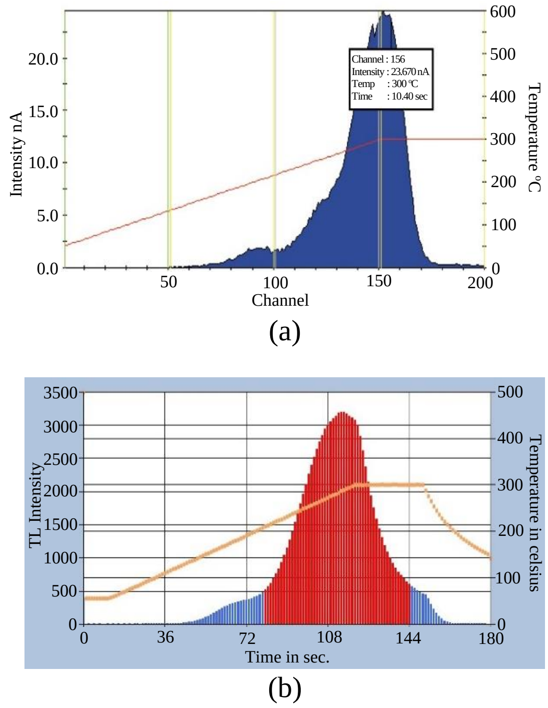
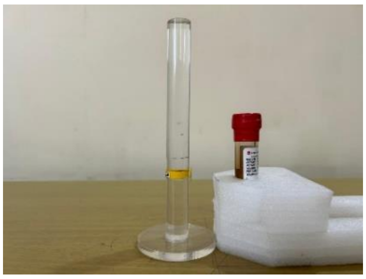


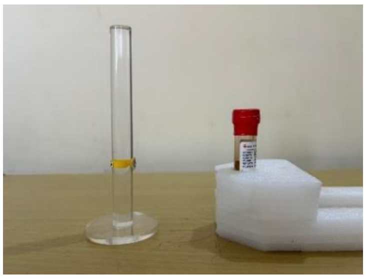
Fig. 2. Appearance of glow curve of dose readings on the TLD-700 (a) and TLD-900 (b) [15,16].

Procedure

Thirty ring dosimeters were prepared for irradiation and six dosimeters were used as controls for each type of TLD. All dosimeters have been annealed. Three dosimeters each were mounted on the rod phantom at a distance of 5 cm, 7 cm, and 10 cm from the surface of Sr-90 beta source in the irradiation angle of 0°. Figure 3 shows the setting of the ring dosimeter irradiation against Sr-90 at a distance of 5 cm and 10 cm. The radioactive source used is a liquid in a vial with an activity of 18.5 MBq in 5 ml of solution. Irradiation is carried out for 24 hours for each distance for both TLD-700 and TLD-900 based ring dosimeters. Dosimeters that have been irradiated and two dosimeters as controls are read using a TLD reader in LTRSM-NRIA and NuklindoLab. Furthermore, the reading of $H_p(0.07)$ is analyzed.



(a)



(b)

Fig. 3. Ring dosimeter irradiation to beta Sr-90 for variation of 5 cm (a) and 10 cm (b).

Three ring dosimeters for each type of TLD attached to the rod phantom were exposed to Sr-90 at a distance of 7 cm for 24 hours. The same irradiation was also carried out for 48 and 72 hours for each of the other 3 dosimeters. The reading of irradiated dosimeters and their control dosimeters was carried out using the TLD reader. Then an analysis of the reading result was done.

Three dosimeters were exposed to Sr-90 for 24 hours at a distance of 7 cm and an irradiation angle of 30°. The same irradiations were carried out at angles of 60°, −30° and −60°. The position of the ring dosimeters at variation of angular irradiation to Sr-90 is shown in Fig. 4. Dose readings of irradiated dosimeters and their control were done in the Dosimetry Laboratory using the TLD reader. The dose reading of $H_p(0.07)$ was analyzed.

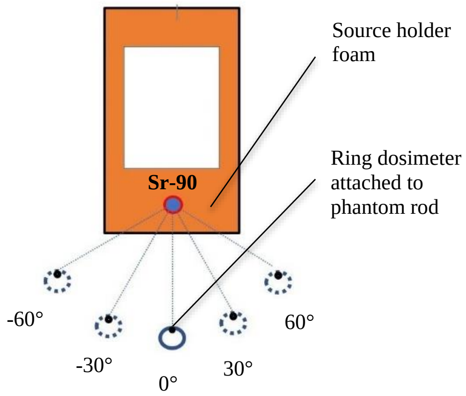


Fig. 4. Setting the position of the ring dosimeters on the Sr-90 exposure with variation in the irradiation angle at 7 cm.

RESULTS AND DISCUSSION

Distance variation

The effect of distance on the $H_p(0.07)$ response of the ring dosimeter for Sr-90 beta irradiation is shown in Fig. 5.

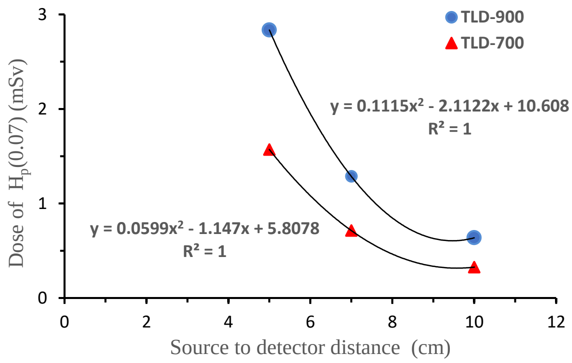


Fig. 5. Curve of the effect to Sr-90 irradiation distance on dose response $H_p(0.07)$ to ring dosimeters.

Figure 5 shows that the relationship curve between source to detector distance and $H_p(0.07)$ dose is polynomial with a correlation factor of 1, both for TLD-700 and TLD-900 based ring dosimeters. The dose response equation is $y = 0.0599x^2 - 1.147x + 5.8078$ and $y = 0.1115x^2 - 2.1122x + 10.608$ for TLD-700 and TLD-900 based dosimeters, respectively. It was seen that the dose response on the TLD-700 based dosimeter was relatively lower at the same exposure distance. This is likely due to the difference in thickness of the window shield/filter that protects the TLD chip on each ring dosimeter. The window shield on the TLD-700 based ring dosimeter is plastic with a thickness of 7 $mg.cm^{-2}$ [9], while the window shield on the TLD-900 based ring dosimeter is 1.38 $mg.cm^{-2}$ mylar. Parks [17] stated that beta radiation emitted by Sr-90/Y-90 was able to penetrate a 0.8 cm polyethylene filter on a TLD-900 based eye dosimeter. Meanwhile, in the Radionuclide Data Sheet of Sr-90 published by Missouri University [18], it is described that Sr-90 has a maximum beta range in air of 1062 cm and 1.1 cm in plastic.

Exposure time

Measurement of Sr-90 dose on TLD-700 and TLD-900 based ring dosimeters for various exposure time is shown in Fig. 6.

The effect of exposure time on the response dose of $H_p(0.07)$ is shown in Fig. 6. It can be seen that the relationship between the dose response of TLD-700 and TLD-900 based ring dosimeters and exposure time is linear with correlation factors of 0.9942 and 0.9999, respectively, at a 7 cm distance from source to detector. The equations of dose $H_p(0.07)$ to exposure time are y = 0.68x + 1E-15 for TLD-700 and y = 1.1767x + 0.1022 for TLD-900 based ring dosimeter. Based on the equations, the greater the exposure time, the greater the range of difference in the dose of $H_p(0.07)$ received by both types of ring dosimeters.

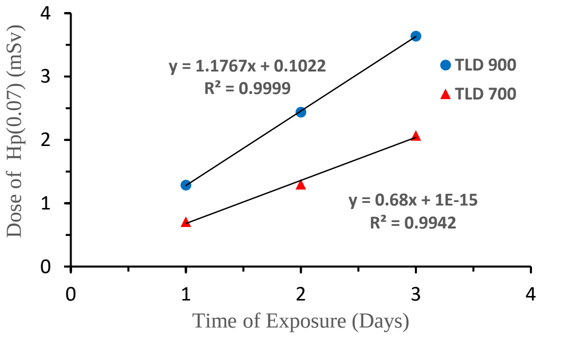


Fig. 6. The relationship of the dose value of $H_P(0.07)$ to the exposure time of Sr-90 to ring dosimeters.

Irradiation angle

The effect of irradiation angle on the the dose response of $H_p(0.07)$ is shown in Fig. 7.

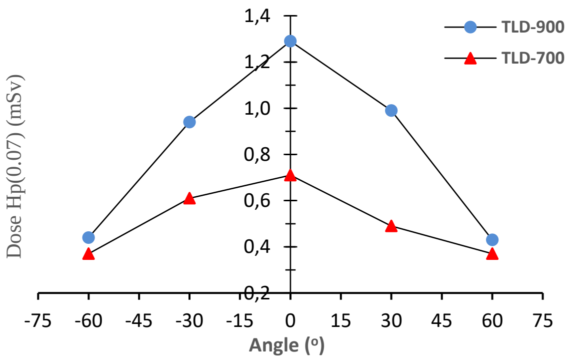


Fig. 7. Effect of Sr-90 angle exposure on $H_P(0.07)$ dose response to ring dosimeters.

The direction in which the radiation beam comes will affect the $H_p(0.07)$ response. Increasing the angle of irradiation reduces Hp(0.07) response. The decrease in $H_p(0.07)$ response in TLD-700 reached 14-31 % for the irradiation angle of ± 30° and 23-27 % in TLD-900 for the same irradiation angle. Meanwhile, the decrease in $H_p(0.07)$ response at the angle of irradiation ±60° reached 48 % for TLD-700 and 66-67 % for TLD-900. The downward trend in $H_p(0.07)$ response on the TLD-900 is relatively larger than that of the TLD-700. This may be due to the difference in the thickness of the window shield/filter that protects the TLD chip on each ring dosimeter resulting in a difference in beta radiation scattering on the dosimeter.

Anggarani et al. [11] in their research on the effect of irradiation angle on TLD-900-based eye dosimeter stated that the relative response decrease for ± 30° angle was 50 % and 84 % for ± 60° angle irradiation. Luo et al. [9] reported a decrease in TLD-700-based extrimities dosimeter response, reaching 7 % at a 30° and 52 % at a 60° irradiation angle. Meanwhile, study on the effect of the Sr-90/Y-90 irradiation angle on the response Hp(0.07) to TLD made from LiF:Mg,Ti was carried out by Sanghu et al. [19] shows a response dropped by approximately 70 % at ± 60°. Tas et al. [20] stated that optimal choice of collimator angle can increase the optimization "freedom" to shape a desired dose distribution.

CONCLUSION

The study of the effect of irradiation distance on the dose response of Hp(0.07) in TLD-700 and TLD-900 based ring dosimeters to Sr-90 beta uncovered polynomial behavior with correlation coefficients of 1 for both of them. The dose response at the variation in irradiation time showed linear behavior with correlation coefficients of 0.9942 and 0.9999 for TLD-700 and TLD-900, respectively. The decrease in $H_p(0.07)$ response at the angle of irradiation of ±30° was ≤ 31 % for TLD-700 and ≤ 27 % for TLD-900. At an irradiation angle of ± 60°, the dose response reduction was 48 % for the TLD-700 and ≤ 67 % for the TLD-900.

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AUTHOR CONTRIBUTION

The first author, E. B. Jumpeno, is the main contributor to this paper. All authors read and approved the final version of the paper.

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